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RECYCLE OF SYNTHETIC WARP SIZES FROM TEXTILE DESIZING WASTEWATER

Carl E. Bryan

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Recycle of Synthetic Warp Sizes from Textile Desizing Wastewater

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Sufficient dewatering of the precipitated CMC - to ten percent solids or higher was accomplished by centrifuging or by the use of a Dual Cell Gravity (DCG) unit (Permutit Co.) alone or, preferably, in combination with a Multi-Roll Press (MRP) unit (Permutit Co.).

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ABSTRACT

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Weaving trials using warp yarns sized with CMC recovered from plant desizing wastewater were as satisfactory as those using warps sized with new CMC. Desizing and dyeing the woven fabrics showed no difference in hand and shade that could be attributed to the recovered CMC. The yarns were blends of polyester and cotton (65:35) and polyester and rayon (65:35).

Sufficient dewatering of the precipitated CMC - to ten percent solids or higher - was accomplished by centrifuging or by the use of a Dual Cell Gravity (DCG) unit (Permutit Co.) alone or, preferably, in combination with a Multi-Roll Press (MRP) unit (Permutit Co.).

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SECTION I

CONCLUSIONS

A process developed earlier on a laboratory scale for precipitating and recovering carboxymethyl cellulose (CMC) from desizing wastes has been found to be applicable to plant-desizing wastes. As in the earlier work, precipitation was accomplished with aluminum sulfate (filter alum).

The CMC-alum precipitate was dewatered to a solids level (10-15%) satisfactory for reuse as a warp size by means of the Dual Cell Gravity (DCG) and Multi-Roll Press (MRP) units, in sequence, of the Permutit Company.

Weaving trials using warp yarns sized with CMC recovered from plant desizing wastes were as satisfactory as those using warp sized with new CMC. Desizing and dyeing the woven fabrics showed that no difference in hand and shade could be attributed to the use of recovered CMC. The yarns were blends of polyester and cotton (65:35) and polyester and rayon (65:35).

Several copolymers of polyvinyl alcohol (PVA) were prepared which were precipitated from dilute solution by aluminum sulfate and ferric chloride. Sizing trials with two of these copolymers followed by tests of the sized yarns with the warp-shed tester, indicated that these, or similar, copolymers may be effective, recoverable warp sizes.

SECTION II

RECOMMENDATIONS

Further work on the removal of warp sizes from textile-desizing wastewater should be concerned with a careful technological and economic evaluation of the several procedures already available. The objective should be to obtain wastewater that is reusable and to leave residues that can be disposed of without harm to the environment. A number of questions remain to be answered and further studies are necessary.

(1) The most commonly used warp sizes - starch, polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC) - have been shown to be biodegradable under the proper conditions. Is biological treatment the most economical method for disposing of these materials? In regard to PVA and CMC particularly, what are the "proper" conditions?

(2) The synthetic warp sizes, CMC and PVA (or a modified PVA), can be removed or recovered from wastewater by several procedures, including precipitation, hyperfiltration, and evaporation. What is the most economic (in the broad sense) method of removal? Should they be removed for disposal (incineration or land disposal) or is it economically favorable to recover them for reuse?

(3) The commercial PVA currently used for sizing warp yarns is not practicably recoverable from desizing wastewater by precipitation. Results on this project show that development of a modified PVA recoverable by precipitation is possible. Is this procedure a "good" way of removing PVA from desizing wastewater?

(4) A large proportion of the COD of CMC-desizing wastewater remains after the CMC is precipitated and removed. Can the materials responsible for this COD be removed economically to leave a reusable wastewater?

SECTION III

INTRODUCTION

The major warp size used in the textile industry is starch which must be removed (scoured) from a fabric before dyeing and contributes heavily to the biochemical oxygen demand (BOD) of textile wastewater. In recent years certain synthetic polymers have been introduced for use as warp sizes; of these materials, polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC) have gained the widest use. Although the cost of these materials is higher than that of starch, they have certain advantages in performance, particularly with yarns of the synthetics and cotton-synthetic blends, which tend to offset this cost differential.

Besides giving increased operating efficiencies, the synthetic warp sizes, having a low 5-day BOD (BOD_5) have been promoted also as a means of reducing the water-pollution potential of desizing wastes. According to one report, CMC has an essentially negligible BOD_5 but shows a steady consumption of oxygen up to the ultimate level of 25% of its weight in about 30 days.[1] According to another report, the BOD_5 for CMC is 4% and the BOD_{30} is 15%, while the BOD_5 of PVA is negligible (1%) and the BOD_{30} is only about 3%.[14] The Federal Water Pollution Control Act Amendments (PL 92-500) of 1972 and the effluent limitation guidelines proposed by the United States Environmental Protection Agency now indicate that BOD_5 is becoming inadequate as the sole measure of organic pollution.[6] Instead the more stringent measure of chemical oxygen demand (COD), or perhaps total organic carbon (TOC), may be required.

The COD of CMC is nearly as high as the COD of starch, however, and the COD of PVA is much higher than that of starch (see Table 1). Therefore, for reducing water pollution as measured by COD, these materials offer no advantage over starch - unless they are more effective than starch and can be used in smaller amounts or unless they can be recovered and reused.

TABLE 1. BOD, COD AND TOD[a] OF COMMON SIZING AGENTS

Sizing Agent	BOD_5 (%)	BOD$_{30}$ (%)	COD (%)	TOD (%)
Starch	64	95	118	118
Carboxymethyl cellulose (CMC)	4	25	93	103
Polyvinyl alcohol (PVA)	1	3	175	182

[a] Theoretical oxygen demand

Starch is readily biodegradable and is removed to a high degree in a well-operating biological waste-treatment system. Previously, CMC and PVA, having a low BOD_5, were assumed to be only slowly and incompletely biodegradable and apparently to pass unchanged through these treatment systems or to be only partially removed by adsorption on the biological mass. Recent investigations on another project sponsored by the United States Environmental Protection Agency, have shown that activated-sludge microorganisms can become acclimated to CMC and PVA, respectively, and effect a high degree of removal of these substances from influents containing them.[3,4] A process was developed on pilot scale for precipitating CMC from desizing wastes with filter alum and recovering and redissolving the precipitate to give a solution potentially suitable for reuse in sizing warp yarns.[3] On the other hand, the recovered CMC may be disposed of as a solid waste without further treatment.

The CMC was carried through five cycles of sizing, desizing, and size recovery, continuing with only the material recovered from the previous step. The trials were carried out on a blended yarn of polyester and cotton (65:35) with an add-on of size of approximately 10% of yarn weight. Nearly quantitative recovery of CMC was obtained by precipitation from the dilute desizing wastewater with filter alum. The precipitated CMC was dewatered by centrifuging, dissolved in dilute sodium hydroxide, and reused. Performance of the recovered CMC on the Callaway slasher was satisfactory. The results obtained with the sized yarns on a warp-shed tester were comparable to those obtained with yarns sized with new CMC for four cycles. On the fifth cycle, however, the results were slightly poorer with the recovered CMC; the shed was higher, the clinging was greater, and there were more "stops". Some of the natural impurities of the cotton and probably the spinning oil used on the polyester were retained by the CMC during recovery, gradually accumulating in each cycle, and undoubtedly were the major if not the sole cause of the final decrease in performance of the recovered CMC as a warp size. They did not affect four cycles of operation, however, and they were not retained by the yarns in any step.

Other researchers have shown that PVA can be recovered in a reusable form from desizing wastewater by hyperfiltration.[2,8,13] Precipitation techniques have not been found applicable to commercial warp-size-grade PVA but are applicable to certain PVA modifications.[3] On the other hand, hyperfiltration might be used with CMC desizing wastewater. The two processes therefore should be compared to find out if one is better or if they might be complimentary.

The results, summarized above, obtained on the earlier EPA project and elsewhere, indicated that more extensive trials should be made in a textile plant to develop a practical procedure for size recovery and to obtain sufficient amounts of recovered material for weaving trials. The Wake Finishing Plant of Burlington Industries agreed to cooperate with us in these trials.

SECTION IV

EXPERIMENTAL STUDIES AND DISCUSSION

RECOVERY OF CMC FROM PLANT DESIZING WASTES

A preliminary trial of size recovery from desizing wastes was carried out at the Wake Finishing Plant of Burlington Industries. Some 3700 yards (3100 lb., approx.) of polyester/rayon (65/35) fabric, woven from warps sized with sodium carboxymethyl cellulose (CMC), was desized continuously in a beck which was divided into three compartments, twelve feet, three feet, and three feet, respectively, in width. The fabric passed first through the twelve-foot section which contained a solution of soda ash (0.1%) and non-ionic surfactant (0.1%), and then through the two three-foot sections, which contained only water. All three compartments were heated to 180°F. Analysis, after desizing, of the liquors in the three compartments for total solids, amount precipitated by alum, and CMC content gave the values shown in Table 2.

TABLE 2. TOTAL SOLIDS AND CMC CONTENT IN FIRST DESIZING LIQUORS

Analysis	Compartment		
	1	2	3
Total solids (%)	0.72	0.36	0.22
Alum precipitate (%)	0.40	0.18	0.12
CMC analysis (%)[a]	0.32	0.13	0.09

[a] Spectrophotometric determination

The CMC in the desizing liquors was flocculated by the addition of a 50% solution of filter alum. The alum solution was added until the pH was lowered to 3.5, a condition found previously to insure complete flocculation of the CMC. Because of the presence of the surfactant, an attempt to pump the CMC slurry from the beck produced an emulsion from which the CMC could not be settled. A portion of the flocculated CMC was collected manually from the first compartment of the desizing beck and taken to North Carolina State University (NCSU) for dewatering by centrifuging. Approximately 200 pounds of water-swollen, salmon-colored material (approx. 20 lb., dry weight) was obtained.

Part (approx. 17.5 lb.) of the recovered, dewatered CMC was dissolved by the addition of sodium hydroxide solution with vigorous stirring using a laboratory homogenizer (Eppenbach). About 2.5 gallons of a smooth, opaque, salmon-colored solution was formed, with a solids content of 10% (by weight), a viscosity of 400 centipoises (160°F) and a pH of 7.9.

Warps containing 252 ends of 32/2 Dacron/Avril (65/35) yarn, identical to the warps in the desized fabric, were sized on a Callaway Slasher with the solution of recovered CMC and, as a control, with a solution of new CMC. Three add-on levels were applied with each of the CMC solutions. A small build-up of size and fiber on the first drying cylinder was noted near the end of the slashing trial with the recovered CMC.

The cause of this build-up is not known but it may indicate the presence of a small amount of water-soluble impurities in the recovered size. Slashing data are presented in Table 3.

TABLE 3. SLASHING DATA FOR NEW AND RECOVERED CMC ON 32/2 DACRON/AVRIL YARN

Test no[a]	Viscosity (Centipoises)	Foaming in size box	Dry can sticking	Shedding at split-rods	Bath solids (%)
1	400	No	No	Slight	10.5
2	at	No	No	Slight	10.5
3	160°F	No	No	Slight	10.5
4	430	No	No[b]	Slight[c]	7.6
5	at	No	No[b]	Slight[c]	7.6
6	180°F	No	No[b]	Slight[c]	7.6

[a] Tests 1-3 were made using recovered CMC.
Tests 4-6 were made using new CMC.

[b] There was shedding on the first drying cylinder. This shed brushed off easily.

[c] The yarn was separating poorly at the split rods. Also, there were broken yarns at this point as a result of the hard split.

The sized warps were tested on a warp-shed tester, a laboratory machine that simulates the action of a loom. The results given in Table 4 indicate that at equivalent add-ons, there was less shedding with warps sized with new CMC. The fibrous content of the shed, however, was lower for the warps sized with recovered CMC. There was no difference in number of stops but clinging was slightly less with warps sized with new CMC. With the recovered CMC, it was found that the higher the add-on, the higher the percent shed after testing. The fibrous content decreased with increasing add-on, suggesting that the recovered CMC contained an appreciable amount of water-soluble impurities which loosely adhered to the sized yarn.

A second trial of size recovery from desizing wastes was carried out at the Wake Finishing Plant. Some 3200 yards of polyester-rayon-spandex (59:37:4) fabric, woven from warps sized with sodium craboxymethyl cellulose (CMC), was desized continuously as a rope in a beck which was divided into three compartments, twelve feet, three feet, and three feet, respectively, in width. Desizing in this case differed from that previously reported in that all the compartments of the beck contained only water, heated to 180°F.

The desizing liquor was pumped from the first compartment of the beck into six cylindrical tanks (total capacity, 500 gal.). As soon as a tank was filled, the proper amount of concentrated (50%) alum solution was added to precipitate the CMC. When the CMC-alum precipitate had settled the supernatant was pumped to a floor drain and the sludge remaining was transferred to a container for storage and transportation to NCSU for recycling. The tanks were filled again with desizing liquor from the beck and the operations of precipitation with alum, settling, removal of supernatant, and transfer of

TABLE 4. WARP-SHED TESTER RESULTS ON 32/2 DACRON/AVRIL YARN SIZED WITH NEW AND WITH RECOVERED CMC

Test No[a]	Add-on (%)	Shed (%)	Fiber in Shed (%)	Cling Rating (%)	Stops 20 yds. (No.)
1	10.4	2.3	31	25+	0
2	9.0	2.4	34	50-	1
3	8.8	2.2	38	50-	0
4	9.0	1.8	64	25	0
5	7.2	1.9	80	50	1
6	6.3	1.9	85	25+	0

[a] Tests 1-3 were made with recovered CMC.
Tests 4-6 were made with new CMC.

CMC-alum sludge were repeated. Each tank was used four times, a total of 24 precipitations, in recovering the CMC from the desizing liquor in the first (12-ft.) compartment of the beck. Because the liquors in the other two compartments had smaller volumes, as well as a lower concentration of CMC, they were not collected for further processing. Small-scale experiments have shown, however, that CMC is precipitated essentially quantitatively by alum from solutions of these low concentrations. The results of analysis of the liquors in the three compartments, after desizing, are shown in Table 5.

TABLE 5. TOTAL SOLIDS AND CMC CONTENT OF SECOND DESIZING LIQUORS

Analysis	Compartment 1	2	3
Total solids (%)	0.72	0.27	0.18
Alum precipitate (%)	0.68	0.17	0.11
CMC content (%)[a]	0.50	0.13	0.10

[a] Spectrophotometric analysis

The precipitated CMC was taken to NCSU for dewatering by centrifuging. Approximately 350 pounds of water-swollen, gray material was obtained, with a dry weight of approximately 35 pounds.

The desized and dried fabric had a slightly stiff hand (feel), indicating that it still retained a small amount of the sizing material. Extraction of a sample of the fabric with Freon showed that the material retained was primarily composed of the wax which was used in small amount in the CMC sizing composition. Scouring with a detergent will most likely be necessary for complete removal of such a size in a rapid, commercial desizing operation. The use of a detergent in CMC desizing, however, will be of consequence in the CMC recovery process only if the CMC-alum sludge must be passed through a pump during recovery and dewatering. There is also some controversy as to whether wax is necessary in CMC sizing compositions.

A third trial of size recovery from desizing wastes was carried out at the Wake Finishing Plant. Some 3000 yards (approx. 2000 lbs.) of rayon-acetate-nylon (47:33:20) fabric, woven from warps sized with CMC and kettle wax, was desized continuously, as a rope, in a beck which was divided into three compartments, twelve feet, three

feet, and three feet, respectively, in width. The fabric passed first through the twelve-foot section which contained a solution of non-ionic detergent (0.1%) and then through the two three-foot sections which contained only water. The first compartment was heated to 170°F, the second to 150°F, and the third to 100°F. Analyses, after desizing, of the liquors in the three compartments for total solids, amount precipitated by alum, and CMC content are shown in Table 6.

TABLE 6. TOTAL SOLIDS AND CMC CONTENT OF THIRD DESIZING LIQUORS

Analysis	Compartment		
	1	2	3
Total solids (%)	0.43	0.19	0.09
Alum precipitate (%)	0.22	0.10	0.04
CMC content (%)	0.21	0.08	0.03

The desizing liquor in the first compartment of the beck was pumped into several large cylindrical tanks (capacities: 50 and 150 gallons). Tanks containing about half of the liquor were treated with a concentrated alum solution in the amount found previously to be satisfactory for precipitation of the CMC. The precipitated material was taken to NCSU for further experimentation. Tanks containing the other half - some still hot (140°F) and some that had been allowed to stand and cool to room temperature - were treated with varying amounts of concentrated ferric chloride solution. In every case the precipitate that formed was finely dispersed and slow to settle in comparison with

that produced with alum. This result substantiates earlier jar tests in the NCSU laboratory.

WEAVING TRIALS WITH RECOVERED CMC

A weaving trial was made using warp yarns sized with the CMC recovered from the desizing wastes. A similar trial was made with warps sized with new, commercial, warp-size-grade CMC (Hercules) as a control. The CMC, dewatered by centrifuging but still highly swollen with water (10-15% dry weight CMC),was dissolved by the addition of sodium hydroxide solution (40%) with good agitation (Eppenbach homogenizer) and heating in a hot-water bath. Approximately eight pounds of dewatered CMC was dissolved in this way to give about eight gallons of solution with a total solids content of 12% and a pH of 8.5. Hot water was added to the concentrated solution to give approximately 15 gallons of sizing solution with a total solids content of 7.3% (CMC content, 5.8%) and a pH of 8.5.

The yarns used in the weaving trials were the same as those comprising the commercial fabric (Burlington) from which the CMC was recovered. The warp yarn was a 35/2 polyester-rayon (65:35) blend; the filling yarn was a 16/1 polyester-rayon (65:35) blend.

Although a number of mechanical steps are involved, weaving may be divided into three operations: warping, i.e. placing the required number of yarns of the required length on a beam; slashing (sizing), i.e. coating the warp yarns with a protective, polymeric film; and the weaving, i.e. formation of a fabric. Data regarding the sizing solutions and the sizing operation are shown in Table 7.

Results of the weaving trials indicate weaving with warp yarns sized with recovered CMC was as satisfactory as that with warp yarns sized with new CMC.

TABLE 7. WEAVING WITH NEW AND RECOVERED CMC: FIRST TRIAL

Sizing and Weaving Data	New CMC	Recovered CMC
Solids in sizing solution (%)	5.4	7.3
CMC content of solids in size (%)	98	79
Viscosity of sizing solution (cps)[a]	180	400
pH of sizing solution	8.0	8.5
Add-on of size (% of yarn weight)	5.0	7.2
Fiber in shed during weaving (%)	60	70

[a] Centipoises at 170-175°F

A second weaving trial was made on commercial looms using warp yarns sized with another batch of CMC recovered from plant desizing wastes. In this case, fabric desizing had been carried out with hot water without any auxiliary chemicals. Solution of the recovered and dewatered CMC was effected as before by the addition of the proper amount of sodium hydroxide solution (40%), with good agitation and heating in a hot-water bath. Approximately ten pounds of dewatered CMC was dissolved in this way to give about ten gallons of solution with a total solids content of 12% and a pH of 8.0. Hot water was added to the concentrated solution to give approximately 18 gallons of sizing solution with a total solids content of 6.8% (CMC content, 5.1%) and a pH of 8.0.

The yarns used in the weaving trials were, as before, the same as those comprising the commercial fabric (Burlington) from which the CMC was recovered. The warp yarn was a 35/2 polyester-rayon (65:35) blend; the filling yarn was a 16/1 polyester-rayon (65:35) blend.

The results obtained from the second weaving trial are shown in Table 8. For comparison, the results obtained from the first weaving trial are shown again, along with those obtained from the control. The performance of the recovered CMC was as good as, if not better than, that of the new CMC used as a control. The construction of the fabric woven was very tight, placing great strain on the warp yarns, and probably accounted for the warp-end breakage.

TABLE 8. WEAVING WITH NEW AND RECOVERED CMC: SECOND TRIAL

Sizing and Weaving Data	New CMC[a]	Recovered CMC	
		1	2
Solids in sizing solution (%)	5.4	7.3	6.8
CMC content of solids in size (%)	98	80	74
Viscosity of sizing solution (cps)[b]	180	400	170
pH of sizing solution	8.0	8.5	8.5
Add-on of size (% of yarn weight)	5.0	7.2	10.5
Number of warp stops during weaving	12	10	6
Fiber in shed during weaving (%)	57	70	72
Fabric woven (yd.)	53	51	44

[a] Control, with warp-size grade CMC (Hercules)

[b] Centipoises at 170-175°F

Further weaving trials were made u ng warp yarns sized with CMC recovered from plant desizing wast s as previously described. The yarn, both warp and filling, was a 4 /1 polyester-cotton (65:35) blend, a composition widely used in the t xtile industry. This yarn was finer than that used in previous wea ng trials and hence provided a more strenous test of the performance f the recovered CMC as a warp size. A similar trial was made wi warps sized with new, commercial CMC (Hercules) as a contro

Solution of the recovered and dewa ered CMC was effected as in previous experiments by the addition the proper amount of sodium hydroxide solution (40%), with g d agitation and heating in a hot-water bath. In one case, approxima ly 10.5 pounds of dewatered CMC was dissolved in this way to give a ut 10 gallons of solution with a total solids content of 7.4% (CMC ontent, 5.2%) and a pH of 7.5. In the other case, approximately n e pounds of dewatered CMC was dissolved with sodium hydroxide to ve eight gallons of solution with a total solids content of 13% and a p of 8.2. This solution was diluted with hot water to give approxima ly 10 gallons of sizing solution with a total solids content of 10.7% MC content, 8.2%) and a pH of 8.2.

The results obtained from these wea ing trials are shown in Table 9. The better performance of the arps in the second trial with recovered CMC apparently can be a ributed to the higher add-on of size.

TABLE 9. WEAVING WITH NEW AND RECOVERED CMC: THIRD TRIAL

(Yarn: 40/1 Polyester-cotton (65:35) blend)

Sizing and Weaving Data	New CMC[a]	Recovered CMC	
		1	2
Solids in sizing solution (%)	7.2	7.4	10.7
CMC content of solids in size (%)	98	70	77
pH of sizing solution	7.5	8.0	8.2
Add-on of size (% of yarn weight)	7.1	10.4	12.3
Number of warp stops during weaving	10	85	11
Fiber in shed during weaving (%)	85	61	54
Fabric woven (yd)	70	47	39

[a] Control with warp-size-grade CMC (Hercules)

DYEING OF FABRICS WOVEN WITH RECOVERED CMC

Weaving trials with a polyester-rayon (65:35) blended yarn, both warp and filling, were described in the preceding part. Portions (25 yd) of the fabrics from each of the three weaving trials, two with recovered CMC and one with new CMC, were desized together in a small beck. The desizing bath was a solution of soda ash (0.1%) and Triton X-100 (0.1%) in water (80 gal). The fabrics were scoured in this bath at 170°F for 20 minutes; then the bath was discharged and the fabrics were rinsed twice in successive baths of warm (130°F) water.

Samples of the three desized fabrics were dyed and heatset in accordance with the following sequences.

A. Polyester dyed only

B. Polyester dyed, heat-set

C. Polyester dyed, heat-set, rayon dyed

D. Rayon dyed only

E. Heat-set, rayon dyed

The polyester component of the fabrics was dyed (A, B, C) with Latyl Blue FLW (C. I. Disperse Blue 27, No. 60767); the rayon component of fabrics was dyed (C, D, E) with Diphenyl Billiant Blue FF (C. I. Direct Blue 1, No. 24410). Fabrics dyed with these dyes tend to show dyeing defects readily. Standard dyeing procedures recommended by dye and fabric manufacturers, and well-known in the trade, were used throughout.

Some of the fabric samples were heat-set (B, C, E) at 390°F for 45 seconds on a tenter frame.

Fifteen different fabric samples were obtained from the dyeing and heat-setting sequences--five from the fabric (1) woven with new CMC, five from the fabric (2) woven with the first batch of recovered CMC, and five from the fabric (3) woven with the second batch of recovered CMC. Swatches (8" x 12") were cut from each of the 15 fabric samples and sewn into five test panels, representing each of the five processing sequences. These panels are represented schematically below.

A	1	2	1	3	2
B	1	2	1	3	2
C	1	2	1	3	2
D	1	2	1	3	2
E	1	2	1	3	2

A cursory examination of the panels by members of the NCSU staff indicated that there was no difference in hand among any of the swatches, nor was there any difference in shade or uniformity of color among the swatches in any panel that could be attributed to the size.

A weaving trial with a 40/1 polyester-cotton (65:35) blend, both warp and filling yarns, using CMC recovered from plant desizing wastes as a warp size, was described above. A similar trial was made at the same time with warps sized with new, commercial CMC as a control. Portions (32 yd) were taken from each of the woven fabrics and split into two-yard samples. These samples were put through serial combinations of two, three, four or five of the processes of desizing, bleaching, cotton dyeing, polyester dyeing, and heat setting. The desizing process, however, was a component of each treatment combination as represented in Table 10. To insure validity of comparison, corresponding experimental samples, woven with recovered CMC, and control samples, woven with new CMC, were always treated together. In addition the two-yard samples were sewn together before each treatment process so that all samples received a given treatment at the same time. The only exception to this procedure was heat setting, which had to be done in two separate batches.

The combinations and sequences of processes used in finishing the fabric samples are shown diagramatically in Figures 1 and 2. The final results are given in Table 10.

Procedures for each of the processes are given as follows:

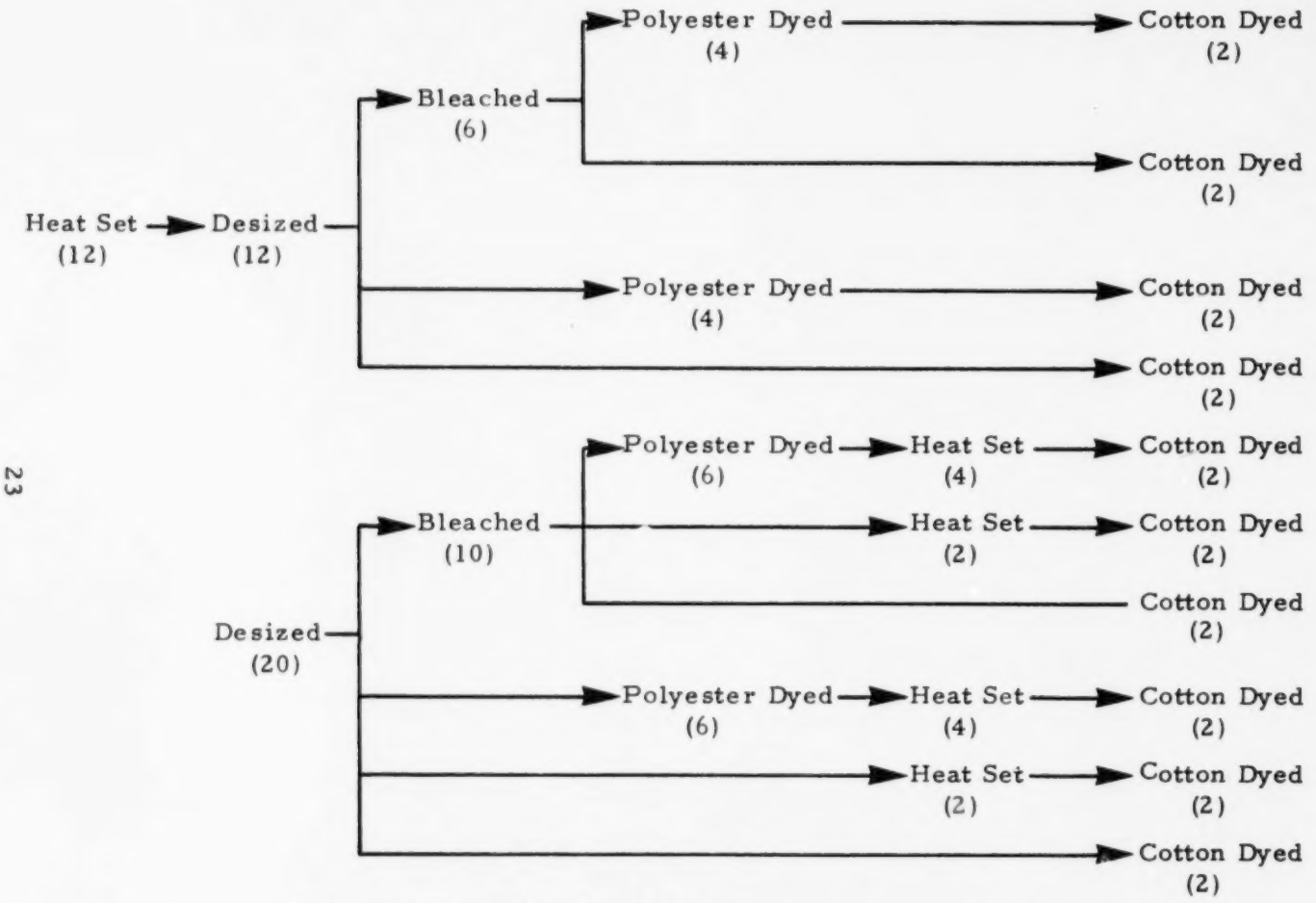

Figure 1. Combinations of processes for treating fabrics.
(Yards of each fabric shown in parentheses.)

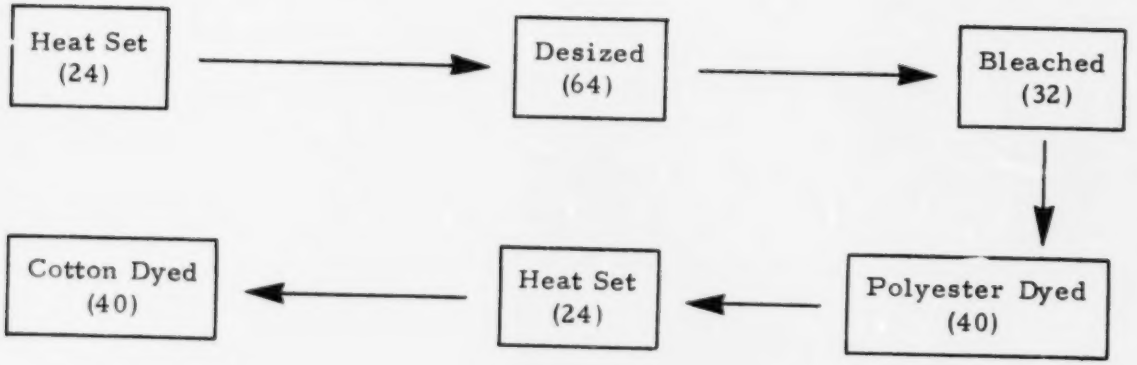

Figure 2. Total yardage of fabric in each treatment process.
(Experimental and control)

TABLE 10. PROCESS SEQUENCE FOR EACH TWO-YARD SAMPLE OF FABRIC

No.	Size	
1	control	desized, bleached, polyester dyed
2	control	desized, bleached, polyester dyed, heatset
3	control	desized, bleached, polyester dyed, heatset, cotton dyed
4	control	desized, bleached, cotton dyed
5	control	desized, bleached, heatset, cotton dyed
6	control	desized, left unbleached, polyester dyed
7	control	desized, left unbleached, polyester dyed, heatset
8	control	desized, left unbleached, polyester dyed, heatset, cotton dyed
9	control	desized, left unbleached, cotton dyed
10	control	desized, left unbleached, heatset, cotton dyed
11	recovered	desized, bleached, polyester dyed
12	recovered	desized, bleached, polyester dyed, heatset
13	recovered	desized, bleached, polyester dyed, heatset, cotton dyed
14	recovered	desized, bleached, cotton dyed
15	recovered	desized, bleached, heatset, cotton dyed
16	recovered	desized, left unbleached, polyester dyed
17	recovered	desized, left unbleached, polyester dyed, heatset

TABLE 10 (continued). PROCESS SEQUENCE FOR EACH TWO-YARD SAMPLE OF FABRIC

18	recovered	desized, left unbleached, polyester dyed, heatset, cotton dyed
19	recovered	desized, left unbleached, cotton dyed
20	recovered	desized, left unbleached, heatset, cotton dyed
21	control	heatset, desize, bleach, polyester dyed
22	control	heatset, desize, bleach, polyester dyed, cotton dyed
23	control	heatset, desize, bleach, cotton dyed
24	control	heatset, desize, left unbleached, polyester dyed
25	control	heatset, desize, left unbleached, polyester dyed, cotton dyed
26	control	heatset, desize, left unbleached, cotton dyed
27	recovered	heatset, desize, bleached, polyester dyed
28	recovered	heatset, desize, bleached, polyester dyed, cotton dyed
29	recovered	heatset, desize, bleached, cotton dyed
30	recovered	heatset, desize, left unbleached, polyester dyed
31	recovered	heatset, desize, left unbleached, polyester dyed, cotton dyed
32	recovered	heatset, desize, left unbleached, cotton dyed

Heat-Setting: The fabric samples were heat set on a tenter frame at 390°F for 45 seconds. The fabric width was held at 38 inches.

Desizing: The fabric samples were desized in a small laboratory beck with a bath solution of soda ash (0.1%) and Triton X-100 (0.1%); the bath ratio was 60:1 (bath to fabric by weight). The bath was held at 170°F for 20 minutes; then it was discharged to the drain and the fabric was given two rinses with hot (130°F) water.

Bleaching: The fabric samples were bleached in a small beck with a solution of hydrogen peroxide (8.0%, on weight of fabric (owf) of 35% H_2O_2) sodium silicate (6.0%, owf) and caustic soda (0.8% owf); the bath ratio was 120:1. The bleaching bath was held at 200°F for 90 minutes; then it was discharged and the fabric was rinsed once with hot (140°F) water, once with a solution of Triton X-100 (0.8% owf) and twice with warm 120°F water.

Dyeing - Disperse Dye: Dyeing was carried out in a jig with a bath ratio of 30:1. A bath solution containing Carolid (0.5%) and Avitone T (0.05%) was heated to 140°F and the fabric was run through four ends (times). The dyestuff (Latyl Blue FLW, C. I. Disperse Blue 27, No. 60767) (1.5% owf) were added to the bath, the temperature was raised to 210°F over a 45-minute period, and dyeing was continued for 60 minutes. The dye bath was discharged and the fabric was rinsed once with water at 140°F, once with a solution of Alkanol H.C.S. (1.0%) at 180°F, and again with water at 140°F. Finally, the fabric was dried on a tenter frame.

Dyeing - Direct Dye: Dyeing was carried out in a jig with a bath ratio of 33:1. The fabric was wet out in the bath solution containing Sequestrene (1.0% owf) and the dyestuff (Diphenyl Brilliant Blue FF, C. I. Direct Blue 1, No. 24410, 1.0% owf) was added. The bath temperature was raised to 210°F over a 30-minute period and dyeing was continued for 45 minutes. Then salt (30%, owf) was added and dyeing was continued for a further 15 minutes before the dye bath was discharged. The fabric was rinsed once with water at 140°F and dried on a tenter frame.

Corresponding pairs of dyes samples, obtained from weaving with new and recovered CMC, were sewn together and examined by several members of the NCSU staff. The opinion was that there was no difference in shade or uniformity of color between the pairs of samples that could be attributed to the size. This result substantiates that reported earlier for dyeing fabric samples woven similarly from polyester-rayon (65:35) blended yarns.

SEPARATING AND DEWATERING PRECIPITATED CMC

In the earlier work on the recovery and reuse of CMC from textile desizing wastes, the CMC-alum floc was allowed to settle, the supernatant was decanted, and the settled floc was dewatered by centrifugation. Satisfactory batch dewatering was obtained with a basket-type centrifuge, 26 inches in diameter (United States Hoffman Machinery Corp.), operating at 1800 rpm. Consultations with other staff members of NCSU as well as industrial representatives leave little doubt that a large, continuous centrifuge would be suitable for dewatering the CMC-alum floc in the plant. Continuous centrifuges are expensive, however.

There are a number of firms that have already developed other equipment for separating and dewatering sludges from biological treatment and from chemical coagulation and trials on the CMC-alum floc were made with some of the equipment of this type. Four types of equipment were evaluated on the pilot scale and are discussed in the following paragraphs.

Rotostrainer® (Hydrocyclonics Corp.)

A sample of CMC desizing waste, from Wake Finishing plant, was shipped to Hydrocyclonics Corporation of Lake Bluff, Illinois, together with instructions for precipitating the CMC with alum. The quantity of this precipitate retained by the Rotostrainer, a rotating screening device, was less than 10% of the quantity recovered in the laboratory by filtration or centrifugation. The openings in the Rotostrainer apparently are too large to retain this type of precipitate.

Hydrasieve® (Bauer Bros. Co.)

The Hydrasieve is a commercial apparatus for continuously and rapidly separating solid particles from most of the liquid phase of a solid-water mixture. It consists of a stationary, slanting screen or sieve over which the mixture is passed in a thin but rapidly flowing layer. The water phase passes through the screen on the way down while the solid particles are retained to fall down the screen into a trough at the bottom.

A small, portable Hydrasieve with a stainless steel screen (6 inches wide, 0.030 - inch mesh), obtained on loan from American Pollution Control, Inc., retained about 50% of the solids from a CMC-alum suspension after one pass. The solids content of the suspension was 0.5% while that of the material retained was 1.8%. The solids

retention with this screen is inadequate and the solids content of the material retained is much too low for preparing a solution suitable for warp sizing.

Trials with another small Hydrasieve (Model 552-3, stainless steel, $6\frac{1}{4}$ inches wide, 0.020-inch mesh screen) gave better results in that 80-90% of the solids from a CMC-alum suspension was retained by the screen upon a single pass. The solids content of the material retained by the screen from a 1% suspension was 4.0-4.5%; this is too low for our purpose and further dewatering would be required.

Vacuum Filter (Rexnord)

A sample of settled CMC-alum sludge (about 1.5% solids), obtained from plant desizing wastes, was shipped to the Rexnord Technical Center in Milwaukee, Wisconsin for trials with a rotary vacuum filter. The results showed that the sludge is filterable but that the resultant filter cake is quite high in moisture content. The best conditions gave a cake with 94% moisture (6% solids). Further dewatering of the cake would be necessary for our purpose. Cake thicknesses were one-fourth inch to five-sixteenth inch and were satisfactory for discharge from the filter cloth.

Dual Cell Gravity (DCG) and Multi-Roll Press (MRP) Units (Permutit Company)

Sufficient dewatering (to 10% solids or higher) of the CMC-alum precipitate was obtained with the Dual Cell Gravity (DCG) and the Multi-roll Press (MRP) dewatering units of the Permutit Company, Division of Sybron Corporation.[10]

The DCG Sludge Dewatering Unit has been used for dewatering all types of sanitary sewage sludges, a wide range of industrial waste sludges, both biological and chemical, and water treatment sludges from clarification and softening. It consists of two separate compartments or cells, a dewatering cell and a cake-forming cell, which are formed by a fine-mesh nylon filter cloth traveling continuously over front and rear guide wheels. A drive-roll and sprocket assembly rotates the cloth and also serves as the separator between the two cells. (Figure 3).

The sludge is pumped into the first cell where the initial dewatering occurs. The water drains rapidly through the filter cloth and the partially dewatered solids are carried from the first cell over the drive-roll separator into the second cell. Here they are rolled continuously and formed into a cylindrical cake of lower water content. The weight of this sludge cake itself presses out additional water. When the cake grows to sufficient size, the excess tumbles over the rim of the second cell to a conveyor belt which carries it to a disposal point.

Dewatering in the DCG unit is accomplished entirely by gravity and the maximum force applied is only that of a few inches of hydrostatic head. This unit can be used with fragile flocs, such as the CMC-alum precipitate, which may be difficult to handle in devices employing larger forces (pressure or vacuum).

"Blinding" of the filter cloth or screen is minimized, both because of the low pressures applied and because of the tendency of the sludge particles to adhere to one another and separate cleanly from the cloth as a cake.

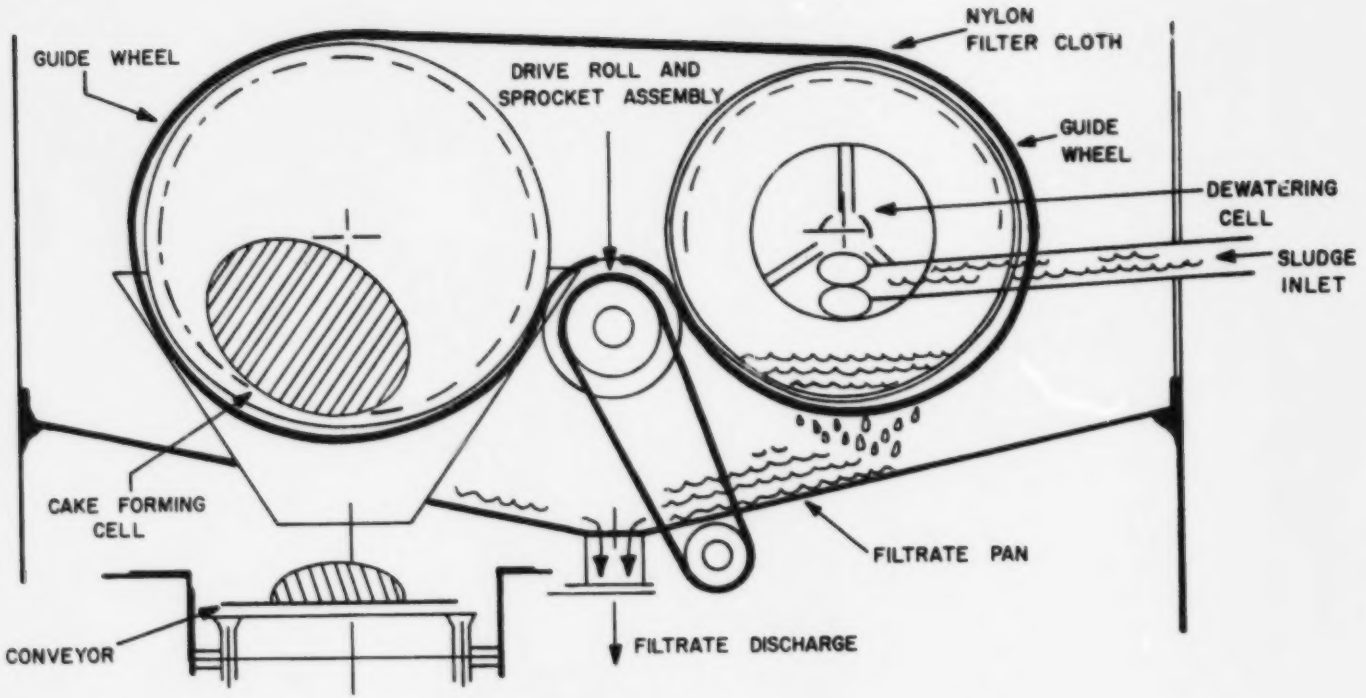

Figure 3. Diagrammatic cross-section of DCG unit.

The Multi-Roll Press (MRP) is a secondary dewatering unit developed for use in combination with the DCG unit and produces cakes with a still higher solids content.[10] It consists of two sets of continuous monofilament-nylon filter belts backed by two neoprene compression belts. The space between the belts and, hence, the pressure applied to the sludge traveling between them, is controlled by four sets of tension rollers which can be adjusted to produce the maximum solids for the type of sludge being dewatered (Figure 4).

The partially dewatered sludge from the DCG unit is discharged directly into the receiving hopper of the MRP Unit where a metering blade volumetrically feeds the cake to the moving filter belts at a rate synchronized with the speed of the belts. The sludge enters a gradual compression area prior to full compression in order to remove the water by degrees; thus maximum pressure can be applied without squeezing the sludge outside the compression area. The belts are inclined, allowing the displaced water to run down to a drip pan. The neoprene compression belts backing the filter belts contain V-shaped treads through which the displaced water travels to the drip pan. A second function of these treads is to allow the sludge to move slightly during compression, facilitating water removal and attaining higher solids content. Removal of the compressed cake at the discharge point is accomplished with a doctor blade. Strategically located sprays backwash the filter and compression belts and any possible solids accumulation points.

In the beginning, it was established in the laboratory by a procedure recommended by the manufacturer, that the DCG unit would probably be suitable for dewatering the CMC-alum sludge. A small

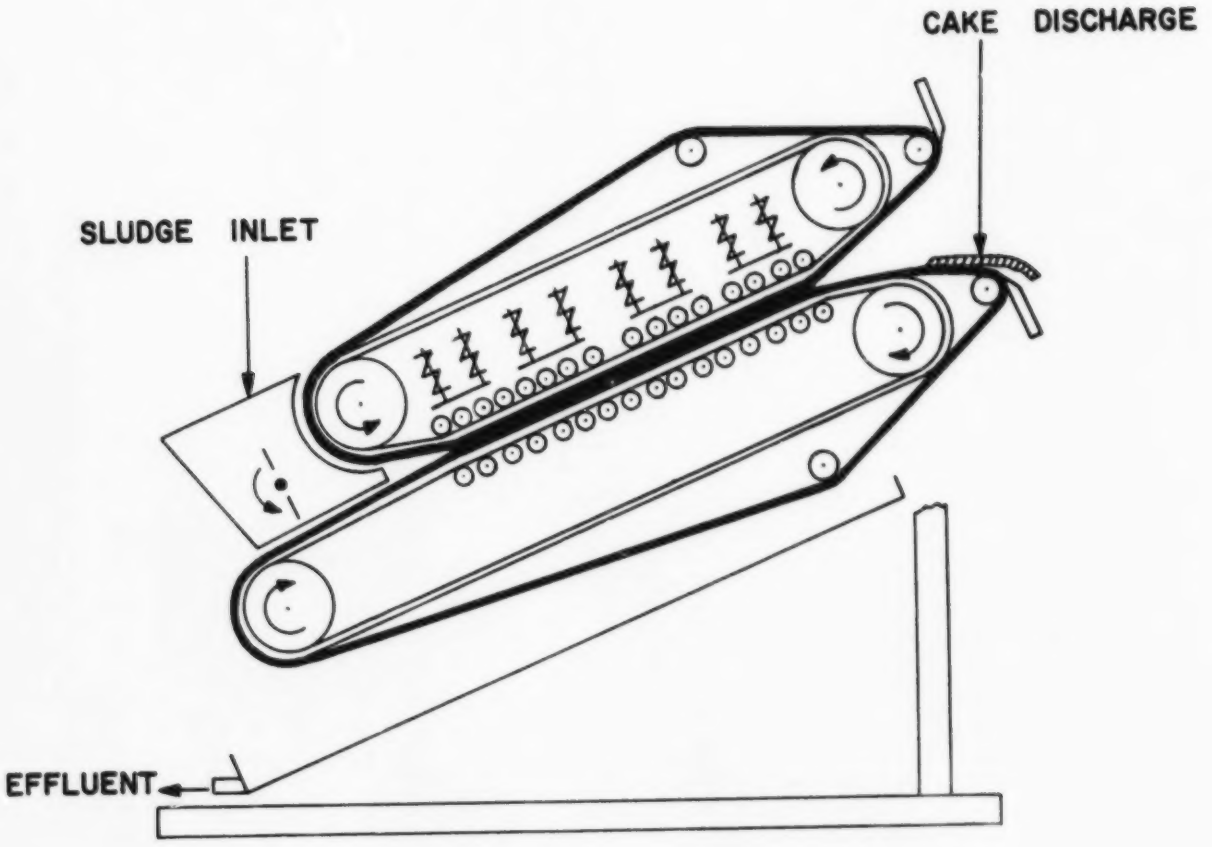

Figure 4. Diagrammatic cross-section of MRP unit.

amount of the sludge was poured onto a piece of coarse nylon fabric held suspended in a U-shape between the two hands. The sludge was rocked or rolled by raising and lowering each end of the fabric alternately. The water phase passed through the fabric while the sludge particles coalesced to form a roll on the fabric. Further dewatering of the sludge continued as the rolling action of the sludge roll was continued. This simple experiment simulates the operation of the DCG unit.

Fabric desizing (Table 11) for the DCG trials was carried out in a beck in the same manner as that described for the preliminary recovery trials. Desizing wastewater for the recovery trials were taken from the first compartment of the beck, which contained the major part of size (Table 12). It was pumped into a 500-gallon tank on the trailer upon which the DCG unit was mounted. The CMC in the desizing wastewater was flocculated by the addition of 50% alum solution, with gentle stirring, to a pH of 3.3-3.5. The mixture in the flocculating tank was then pumped at a suitable rate onto the DCG screens. When the flocculating tank was empty, more desizing wastewater was pumped in and the sequence of flocculation and dewatering was repeated.

A certain amount of trial-and-error experimentation was necessary before the best operating conditions for the DCG unit were found. The variables involved were the concentration of the CMC sludge, the rate of pumping the sludge onto the DCG screens, the porosity of the DCG screens, the rate of rotation of the screens.

TABLE 11. PLANT DESIZING TRIALS WITH FABRICS SIZED WITH CMC

Run no.	Fabric composition	Yards fabric
1	Polyester-rayon-spandex (68:30:2)	3720
2	Polyester-rayon-spandex (59:37:4)	3165
3	Rayon-acetate-nylon (47:33:20)	3020
4	Polyester-rayon (65:35)	3710
5	Polyester-rayon (65:35)	2220
6	Polyester-rayon-acrylic (62:36:2)	2080
7	Polyester-rayon-acrylic (62:36:2)	4860
8	Polyester-rayon-acrylic (62:36:2)	9210
9	Polyester-rayon-acrylic (62:36:2)	5720

TABLE 12. TOTAL SOLIDS (TS) AND CMC CONTENT[a] OF PLANT DESIZING LIQUORS USED IN PRECIPITATING AND DEWATERING TRIALS (PER CENT)

Run no.	Beck Compartment 1		2		3	
	TS	CMC	TS	CMC	TS	CMC
1	0.72	0.32	0.36	0.13	0.22	0.09
2	0.72	0.50	0.27	0.13	0.18	0.10
3	0.43	0.21	0.19	0.08	0.09	0.08
4	0.69	0.29	0.36	0.12	0.33	0.07
5	0.45	0.18	0.16	0.06	0.11	0.03
6	0.36		0.08		0.03	
7	0.28		0.07		0.12	
8	0.69		0.46		0.32	
9	0.52		0.16		0.13	

[a] Determined spectrophotometrically [5, 9]

The following observations were made regarding the operation of the DCG unit.

(1) A sufficient amount of solid material to form a roll must be on the screens before they begin to function properly. Smaller amounts tend to cling to the screens and cause "blinding".

(2) The optimum rate of addition of the solid-liquid mixture from the precipitating tank to the DCG screens in six-to-eight gallons per minute. Faster rates cause over-flowing without permitting the water to pass through the screens.

(3) Eighty-mesh or 100-mesh screens are better for dewatering the CMC-alum precipitate than a 40-mesh screen.

When the rolls of partially dewatered CMC-alum precipitate become large enough, the excess tumbles over onto a conveyor belt which discharges it to the MRP unit for further dewatering. The operation of this unit was described above but the following observations were made in the trials with this particular material.

(1) If the degree of dewatering of the solid introduced is not high enough (8-9% solids in the present case) the MRP unit is not effective and gives essentially no further dewatering.

(2) The pressure on the rolls is important and must be adjusted to fit the nature of the solid to be dewatered. The CMC-alum precipitate is fragile and too much pressure, in attempts to attain higher degrees of dewatering, only causes "blinding" of the screens, results in little or no dewatering and requires cleansing of the screen.

The solids contents of the CMC-alum precipitates after dewatering with the DCG and the MRP units in sequence are given in Table 13.

TABLE 13. SOLIDS CONTENT OF CMC-ALUM PRECIPITATES DEWATERED WITH DCG AND MRP UNITS IN SEQUENCE

Run no.	Solids in cake (%)	
	DCG	MRP
6	9.0	14.6
7	8.4	10.5
7	8.7	11.5
7	9.0	12.0
7	9.7	12.1
7	9.6	11.8
8	9.1	14.3
8	8.9	14.1
9	7.3	11.5
9	6.5	10.8
9	7.2	10.4
9	9.8	15.4
9	6.4	13.3
9	8.6	13.1

The fabrics desized in the series of trials made in this work had been sized with a mixture of CMC and kettle wax. Desizing was accomplished with a hot solution of non-ionic detergent (0.1%) and sodium carbonate (0.1%). The desizing liquors therefore consisted of a solution of CMC and the detergent and a suspension of the wax. Precipitation of the CMC with alum left the detergent and the wax, as well as the spinning oils, in solution or suspension in the supernatant.

Determination of chemical oxygen demand (COD) showed that while a sizable portion of the organic material was removed from the desizing liquor by precipitation of the CMC the major portion remained. (Table 14).

TABLE 14. COD OF DESIZING LIQUORS BEFORE AND AFTER PRECIPITATION WITH ALUM

	COD (mg/l)	
Run no.	Before Precipitation	After Precipitation
6	4710	3820
7	4300	2980

STABILITY OF CMC DURING RECOVERY AND STORAGE

In any recycling process, attention must be given to the accumulation of impurities which, entering each cycle in only small amounts, may eventually reach harmful proportions. A good example is the natural impurities of cotton which are removed from fabrics of cotton and cotton blends during desizing and are partially precipitated with the CMC during size recovery.

The instability of the size itself under the conditions of recycling could also introduce impurities in the recovered size. A partially degraded material would be less active of course and the degradation products, unless removed, would sooner or later render the recycled material useless as a warp size. The prime example is starch which is always degraded during desizing, either biologically (enzymatically) or chemically, and cannot be recycled at all.

In the case of the synthetic size CMC, both the biological and chemical stability during recovery and storage must also be considered.

The hydrolysis of cellulose and cellulose derivatives under the influence of strong acids and alkalis, particularly at elevated temperatures, is well known, of course, and must receive attention in any process for recycling CMC.

When work on this project was begun, several papers had appeared on the biodegradation of CMC under laboratory conditions. Freeman, Baillie, and Macinnes[7] found that solutions of CMC in tap water underwent a loss in viscosity upon standing at room temperature for a month in the absence of a bacteriostat. They isolated gram-negative bacteria which grew rapidly in aqueous media containing CMC as the only carbon source, again with a resultant loss of solution viscosity.

In a study of the susceptibility of cellulose derivatives to attack by a fungus, Myrothecium verrucaria, Siu, Darby, Burkholder and Barghoorn found that CMC of low degree of substitution (DS) was metabolized.[12]

Reese, Siu, and Levinson, using a number of strains of bacteria and fungi, found that the growth of most microorganisms was very good on CMC preparations of low DS; when the DS was above 1.0, however, growth was slight.[11]

Accelerated enzymic degradation studies by Wyrick[15] of a series of six CMC's varying in DS from 0.41 to 2.45 showed that stability improves with increasing substitution and that the sample with DS of 2.45 was essentially refractory to enzymic attack.

Thus, the published work indicates that CMC solutions, or moist CMC, of warp-size grade (DS 0.7), should not be stored for lengthy periods in the absence of a bacteriostat nor should the pH be allowed to rise too high by too rapid addition of sodium hydroxide when the recovered CMC is redissolved with heating for reuse.

That CMC from desizing wastewater can be recovered and reused without significant degradation is evidenced by the work reported here. When the recovered CMC was dissolved to give a sizing solution with a solids concentration approximately the same as that of the original CMC sizing solution, the viscosity of the two solutions was approximately the same also.

Polyvinyl alcohol (PVA) is also biodegradable[4], although perhaps less readily than CMC, and similar considerations apply to its recovery for reuse.

ECONOMIC ASSESSMENT OF RECOVERY PROCESS

The power requirement for each DCG-100 unit is 2.5 horsepower (hp). Since 500 gallons of precipitated-CMC sludge can be dewatered in 90 minutes, 1000 gallons can be dewatered in 180 minutes, or three hours. Thus, dewatering 1000 gallons of sludge requires

$$3 \times 2.5 \times 750 = 5595 \text{ watt-hours} = 5.6 \text{ kilowatt-hours (kwh)} \quad (1)$$

The power requirement for an MRP-100 unit is 0.75 horsepower so that further dewatering of the cake produced by the DCG unit from 1000 gallons of sludge, assuming three hours of continuous operation, requires

$$3 \times 0.75 \times 750 = 1688 \text{ watt-hours} - 1.7 \text{ kwh} \quad (2)$$

Thus, the electrical energy required to operate the DCG and MRP units in tandem for three hours to dewater 1000 gallons of precipitated-CMC sludge is:

$$5.6 + 1.7 = 7.3 \text{ kwh} \tag{3}$$

The cost of additional electrical energy to a plant already using a large amount is a little difficult to calculate since it depends on the total amount used as well as on the peak power demand. A rate schedule in effect at present by the Carolina Power and Light Company for plants using 50-1000 kw of power is as follows:

$120.00 for first 50 kw of billing demand (4)

2.15 per kw for each addition kw of billing demand (5)

1.10¢ per kwh for first 50,000 kwh (6)

1.02¢ per kwh for next 400,000 kwh (7)

0.90¢ per kwh for all additional kwh (8)

The additional billing demand for a relatively large plant like Wake Finishing would be:

$$(2.50 + 0.75) \times 750 = 2438 \text{ watts} = 2.5 \text{ kw} \tag{9}$$

The additional billing-demand cost would be:

$$3 \times 2.15 = \$6.45 \text{ per month} \tag{10}$$

If the dewatering units were used eight hours per day for a 22-day month the pro rata increase would obviously be less than 7¢ per hour of operation.

Thus, the cost of electrical energy could be set at approximately 7¢ per hour, or conservatively, at 10¢ per hour. The cost for dewatering 1000 gallons of precipitated-CMC sludge would then be:

$$0.10 \times 7.3 = \$0.73 \qquad (11)$$

Approximately 6000 ml of alum solution (17% Al_2O_3 basis) is required for 500 gallons of desizing liquor, or 12,000 ml for 1000 gallons. This amount of alum solution weighs:

$$12,000 \times 1.4/454 = 37 \text{ pounds (lbs)} \qquad (12)$$

The cost of liquid alum (17% Al_2O_3) in carload lots at present (January 1975) is \$62 per ton or \$0.031 per pound. Thus, the cost of the alum required for recovering the CMC from 1000 gallons of desizing liquor is:

$$37 \times 0.031 = \$1.15 \qquad (13)$$

A reasonable average value for the concentration of CMC in desizing liquor is 0.3 per cent and, since it has been shown that the CMC can be precipitated quantitatively from such dilute solutions, the amount of CMC (dry basis) that can be recovered from 1000 gallons of desizing liquor is:

$$1000 \times 8.34 \times 0.003 = 25 \text{ lbs.} \qquad (14)$$

The cost of warp-size grade CMC is currently (January 1975) about \$0.54 per pound, so that the CMC recovered from 1000 gallons of desizing liquor can be used in place of new CMC costing:

$$25 \times 0.54 = \$13.50 \qquad (15)$$

The operating costs in recovering and dewatering the CMC from 1000 gallons of desizing liquors is therefore:

$$\$1.15 + 0.73 = \$1.88 \qquad (16)$$

Thus, there appears to be a considerable economic incentive for recycling the CMC in desizing wastes, even if it is recycled only once.

RECOVERY OF POLYVINYL ALCOHOL (PVA) FROM DESIZING WASTES

The work with polyvinyl alcohol (PVA) has not progressed as far as that with CMC. An attractive procedure was not found for precipitating and recovering the conventional warp-size-grade PVA from desizing wastes. A number of materials that will insolubilize PVA are reported in the literature but larger amounts of precipitant are required than are practical.

Several modified PVA's have been prepared which are precipitated from dilute solution by filter alum. These materials were prepared by the alkaline hydrolysis of copolymers of vinyl acetate with relatively small amounts of acidic monomers or of easily hydrolyzed derivatives of acidic monomers. The copolymers of vinyl acetate were prepared by the emulsion copolymerization of vinyl acetate with the selected comonomers.

Two of the modified PVA's, which were precipitated quantitatively from solution by filter alum, were evaluated as warp sizes on the Callaway slasher and the warp-shed tester. These two PVA's were obtained from the alkaline hydrolysis of (1) the copolymer of vinyl acetate and methyl crotonate (90:10 monomer feed) and (2) the ter-polymer of vinyl acetate, methyl acrylate and dibutyl maleate (90:5:5

monomer feed). The performance of the modified PVA's during slashing was satisfactory and the results obtained with the sized yarns on a warp-shed tester were equivalent to those obtained with yarns sized with a commercial warp-size grade PVA (see Table 15).

TABLE 15. WARP-SHED TESTER RESULTS ON YARNS SIZED WITH COMMERCIAL PVA AND WITH MODIFIED PVA

Warp size	Commercial PVA (Vinol 540)		Modified PVA (Vinyl alcohol-crotonic acid copolymer)			Modified PVA (Vinyl alcohol-acrylic acid-dibutyl maleate copolymer)		
Concentration of size (%)	5.0	6.6	3.8	5.0	6.4	4.4	5.1	6.3
Size Add-on (%)	4.8	7.4	3.5	5.3	7.3	4.0	5.4	7.5
Shed (%)	1.0	0.6	0.8	0.7	0.6	1.1	1.0	0.7
Fiber in shed (%)	80	50	73	51	40	81	69	50
Stops	0	1	0	0	0	1	0	0
Clinging ratio (%)	25	50+	25	50	50+	25	50+	50+
Warp tested (%)	20	20	20	20	20	20	20	20

SECTION V

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SECTION VI

PUBLICATIONS

A preliminary report of the work on this project was presented at a Symposium of the American Association of Textile Chemists and Colorists on the Textile Industry and the Environment in Washington, D. C., May 22-24, 1973. It was published in the proceedings of that symposium.

SECTION VII

APPENDIX

Conversion Factors

1 inch (in) = 2.540 centimeters (cm)

1 foot (ft) = 30.48 cm

1 yard (yd) = 0.914 meters (m) = 91.44 cm

1 cm = 0.394 in

1 m = 1.094 yd = 3.281 ft = 39.37 in

1 pound (lb) = 0.454 kilograms (kg) = 453.6 grams

1 kg = 2.205 lb

1 gallon (gal) = 3.785 liters (l)

1 l = 0.264 gal

$^{\circ}F = 9/5\ (^{\circ}C) + 32^{\circ}$

$^{\circ}C = 5/9\ (^{\circ}F - 32^{\circ})$